Quantitative Chemical Mass Transfer in Coastal Sediments During Early Diagenesis

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LONG-TERM GOALS

The long-term goal of this study is to develop a better mechanistic and quantitative understanding of the effects of biologically-enhanced transport, mineralogy, sediment fabric, and particle surface chemistry on biogeochemical reactions occurring in coastal sediments. Specifically, we plan to integrate quantitative expressions of the strongly coupled effects of bioirrigation, bioturbation, mineralogy, and sediment fabric on chemical mass transfer from field and laboratory mesocosm studies using numerical modeling.

OBJECTIVES

The short term objective during FY01 was to (1) achieve a better understanding of the bio-geologic dynamics of estuarine sediments by quantitatively describing the relationship between bioturbation, sediment physical properties, and permeability, (2) to improve the accuracy of EMT as a method to compute the permeability coefficient by analyzing pore space statistics, and (3) to accurately measure permeability from whole-tank mesocosm permeameters and to determine the effect of bioturbation on permeability from these permeameters.

APPROACH

The approach is an integration of field sampling, controlled experiments in laboratory mesocosms, image analysis and numerical modeling. Laboratory mesocosms provide an environment where time-series studies of sediment characteristics including sediment behavior (e.g., aggregation, disaggregation, resuspension, remolding and compaction), properties (e.g., porosity, density and permeability) and microfabric can be studied under controlled conditions. The mesocosms offer a unique opportunity to study the relationship between bioturbation and permeability by constructing the tanks to function as a permeameter rather than relying on traditional core samples that are disturbed and do not properly characterize the burrow volume. The tank sediments are derived from estuarine bottom sediments at our field site and populated with only one species of bottom fauna at a time in order to limit variables and aid in our interpretation of field data.

WORK COMPLETED

- The integration of field and laboratory sampling, laboratory analysis, image analysis, and numerical modeling to show that permeability in heavily bioturbated sediments is controlled by burrow density, not matrix permeability and that burrowing serves to increase permeability.

- The effective medium theory proves to be a useful tool in quantifying the relationship between bioturbation and sediment permeability provided that a good statistical representation of the model parameters is given.

- Whole-tank mesocosm analysis of permeability is ongoing, but has been expanded to include the mud shrimp Callianassa in addition to Schizocardium sp. See initial results below.

RESULTS

The physical reworking of sediment as a result of burrowing homogenizes the upper 15cm and serves to increase sediment permeability. The effect of bioturbation is detectable by laboratory, in-situ, and EMT modeling methods Burrow density, not matrix permeability, controls permeability in heavily bioturbated sediments. The EMT proves to be a useful tool in predicting permeability of fine-grained estuarine sediments provided that a good statistical representation of the model parameters is given. Small pore throats as determined by a statistical analysis of the pore parameters is the controlling factor in EMT estimations of permeability. As a result, the harmonic mean (as opposed to the arithmetic mean) for averaging the pore throat radius and the inter-connectivity of those throats best represents the pore throat size distribution for estimating permeability based on the EMT.

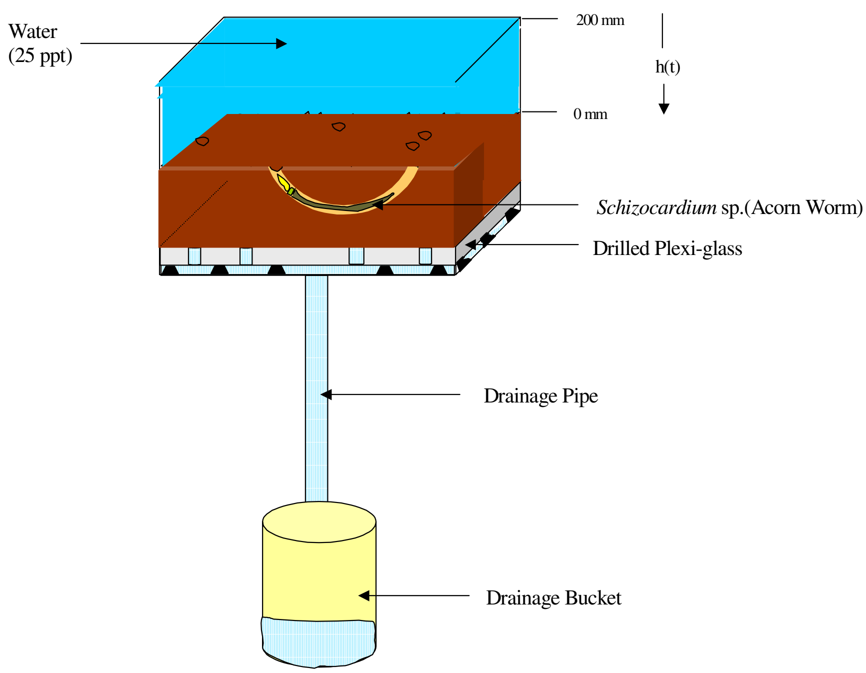

Figure 1. Schematic of the whole-tank mesocosm permeameter. Tanks like this one have been constructed and currently contain Acorn worms and Callianassa shrimp colonies.

Since field cores and even laboratory mesocosm cores do not properly characterize the volume of burrows and are usually disturbed during handling, whole-tank permeameters were constructed to measure burrow influence on permeability (Fig. 1). One tank was filled with mud and populated with Schizocardium sp. at a population density of 430/m2. A second tank was filled with muddy sand and populated with the mud shrimp *Callianassa* at a population density of 31/m^2. Permeability increased

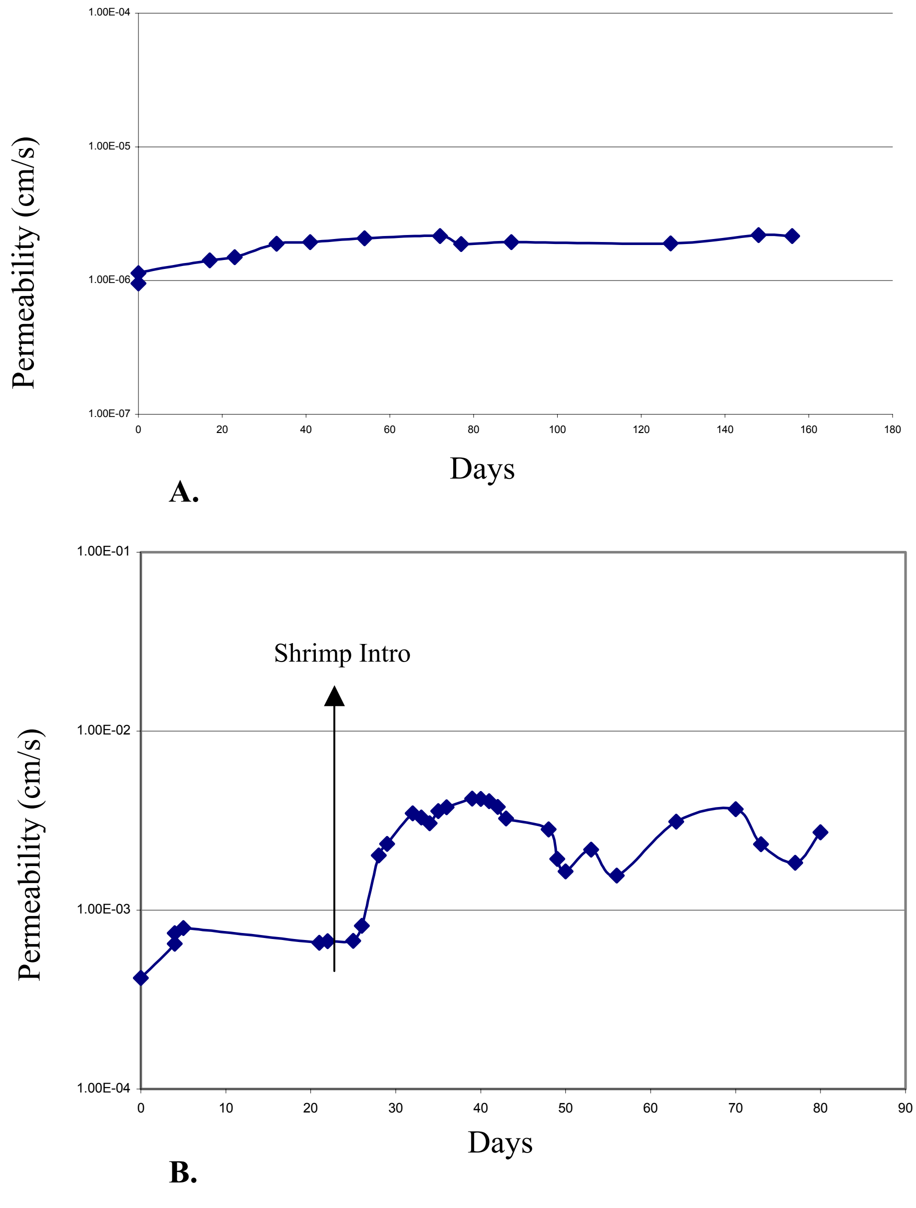

Figure 2. Change in permeability over time after the introduction of Acorn worms (A) and Callianassa shrimp (B). Day 0 in (A) represents measurements taken prior to worm introduction whereas day 0 in (B) represents the first day of the experiment; shrimp introduction occurred on day 25.

only slightly as a result of Acorn worm bioturbation. However, permeability increased dramatically (an order of magnitude) only six days after shrimp introduction. The initial increase in permeability in the Callianassa tank probably is a result of the sediment becoming saturated as water is allowed to drain through the substrate. Subsequently, permeability decreases slightly due to compaction and then increases dramatically after shrimp introduction. These experiments are work in progress.

IMPACT/APPLICATIONS

A better understanding of biologically-enhanced transport during shallow diagenesis will allow us to better model and predict the fate and transport of particles and associated pollutants. By concentrating on fine-grained sediments over the next few years, we hope to make a significant contribution to harbor pollution solutions. In addition, by understanding the effect of fabric changes during diagenesis, we will be able to better predict sediment physical and geoacoustic properties of interest to the MCM community, (predicting mine burial in shallow coastal regions) and the acoustic community for modeling acoustic propagation.

TRANSITIONS

N/A

RELATED PROJECTS

1. Co-funded efforts by Bentley, Koretsky, and Furukawa
2. Biogeochemistry of salt-marsh sediments, by Dr. Joel Kostka (Florida State University)
3. NRL 6.1 core: Microenvironmental Studies (Lavoie)
4. NRL 6.1 core: Evolution of Organic Matter and Clay Associations (Furukawa)

PUBLICATIONS

Vaughan, W.C., Easley, D.H., and Lavoie, D.L., in revision, Averaging Pore Statistics of 2-D Images For Predicting Permeability. Submitted to the Journal of Hydraulic Engineering.

Vaughan, W.C. and Lavoie, D.L., in review, The Quantitative Effects of Bioturbation on Permeability (k) in Fine-Grained Estuarine Sediments. Submitted to Marine Geology.

Furukawa, Y., Bentley, S. J. and Lavoie, D. (2001) Bioirrigation modeling in experimental benthic mesocosms. Journal of Marine Research 59, 417-452.

Abstracts/Presentations

Lavoie, D.L., Vaughan, C., and Easley, D.H., 2000, Quantitative Effects of Bioturbation on Permeability Determined Using a Whole-Tank Permeameter. Eos, Transactions, 2000 Fall Meeting, American Geophysical Union, Vol. 81, No. 48, p. F650.